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A ROTATING ELECTRIC MACHINE AND METHOD OF MANUFACTURING SUCH A MACHINE

Ins. B1

~~In a first aspect the present invention relates to a rotating electric machine of the type described in the preamble to claim 1, such as synchronous machines and normal asynchronous machines as well as dual-fed machines, applications in asynchronous static current converter cascades, outer pole machines and synchronous flow machines.~~

Ins. B2

~~In a second aspect the invention relates to a method of the type described in the preamble to claim 13.~~

In the present application the terms "radial", "axial" and "peripheral" constitute indications of direction defined in relation to the stator of the machine unless expressly stated otherwise. The term "cable lead-through" refers in the application to each individual length of the cable extending through a slot.

The machine is intended primarily as generator in a power station for generating electric power. The machine is intended for use at high voltages. High voltages shall be understood here to mean electric voltages in excess of 10 kV. A typical operating range for the machine according to the invention may be 36 to 800 kV.

Similar machines have conventionally been designed for voltages in the range 6-30 kV, and 30 kV has normally been considered to be an upper limit. This generally means that a generator must be connected to the power network via a transformer which steps up the voltage to

the level of the power network, i.e. in the range of approximately 100-400 kV.

Although the predominant technology when supplying current to a high-voltage network for transmission, subtransmission and distribution, is to insert a transformer between the generator and the power network as mentioned in the introduction, it is already known to endeavour to eliminate the transformer by generating the voltage directly at the level of the network. Such a generator is described in US-4 429 244, US-4 164 672 and US-3 743 867.

A cconductor is known through US-5,036,165, in which the insulation is provided with an inner and an outer layer of semiconducting pyrolized glassfiber. It is also known to provide conductors in a dynamo-electric machine with such an insulation, as described in US-5,066,881 for instance, where a semiconducting pyrolized glassfiber layer is in contact with the two parallel rods forming the conductor, and the insulation in the stator slots is surrounded by an outer layer of semiconducting pyrolized glassfiber. The pyrolized glassfiber material is described as suitable since it retains its resistivity even after the impregnation treatment.

By using high-voltage insulated electric conductors, in the following termed cables, with solid insulation similar to that used in cables for transmitting electric power in the stator winding (e.g. XLPE cables) the voltage of the machine can be increased to such levels that it can be connected directly to the power network without an intermediate transformer.

The concept generally requires the slots in which the cables are placed in the stator to be deeper than with conventional technology (thicker insulation due to higher voltage and more turns in the winding). This entails new problems with regard to cooling, vibrations and natural frequencies in the region of the coil end, teeth and winding.

Securing the cable in the slot is also a problem - the cable must be inserted into the slot without its outer layer being damaged. The cable is subjected to currents having a frequency of 100 Hz which cause a tendency to vibration and, besides manufacturing tolerances with regard to the outer diameter, its dimensions will also vary with variations in temperature (i.e. load variations).

The present invention relates to the above-mentioned problems associated with avoiding damage to the exterior of the cable during insertion into the stator slots and avoiding wear against the surface caused by vibration during operation. There is particular risk of damage at the insertion point where the cable may be damaged against the edge between the slot and the end surface of the stator. The cable may also be damaged if it is inserted askew or eccentrically in the slot. Even during operation there is risk of damage where the cable passes the end surface of the stator. Especially in the event of angle or centring errors, said edge may rub against the outer semiconducting layer of the cable, due to the relative rigidity of the cable, thereby damaging it.

Against this background, the object of the present invention is to eliminate or at least reduce the risk of damage to the cable where it exits at the end surface

of the stator in a rotating electric machine capable of working in the high voltage range.

Ins. B3 ~~According to a first aspect of the invention this is~~ achieved by providing a rotating ~~electric~~ machine of the type described ~~in the~~ preamble to claim 1 with the special ~~features~~ defined in the characterizing part of ~~this claim.~~

Such cuff means reduces the risk of damage when the cable is wound since the cuff prevents the outer semi-conducting layer from coming into contact with the edge of the slot wall at its insertion, and also ensures that the cable is guided into the slot centrally and straight. The risk of damage during operation is also reduced since the cuff can be made of a softer material than the stator and therefore acts as pressure equalizer.

In one preferred embodiment the cuff means extends in radial direction over a plurality of cable lead-throughs, preferably all cable lead-throughs in the slot, and has a profile corresponding to the profile of the slot. This provides stable and reliable securing.

The advantages of the invention are particularly significant when the slots have alternating wide and narrow parts, their profiles therefore resembling a bicycle chain, since the slot wall then surrounds a relatively large part of each cable lead-through. A machine having such slot profile thus constitutes a preferred embodiment.

It is advantageous to make the cuff means of an elastic material. This should be free from process oil and may suitably be silicon rubber. The elasticity of the ma-

terial facilitates guiding the cable and to a great extent exploits the opportunity of achieving pressure equalization at the exit points.

In another preferred embodiment the cuff means is provided at its inner end with a collar protruding into a recess in the slot. This offers a simple and economical way of applying the cuff and achieves reliable retention of the cuff in the slot.

With a view to facilitating insertion of the cable, the inner profile of the cuff preferably widens somewhat towards the end plane of the stator. This also contributes to a gentle exit of the cable, thereby further reducing the risk of damage during operation.

In a further preferred embodiment the cuff means is arranged to seal against both cable and slot wall. A sealed space is thus formed inside the slot which can be filled with support compound sprayed into the slot and solidified therein. In some cases this may be an expedient manner of supporting the cable in the slot.

The invention is in the first place intended for use with a high-voltage cable of the type built up of an inner core having a plurality of strand parts, an inner semiconducting layer, an insulating layer surrounding this, and an outer semiconducting layer the latter, and its advantages are particularly marked here. The invention refers particularly to such a cable having a diameter within the interval 20-200 mm and a conducting area within the interval 80-3000 mm^2.

In the arrangement according to the invention the windings are preferably of a type corresponding to cables with solid, extruded insulation, such as those used

nowadays for power distribution, e.g. XLPE-cables or cables with EPR-insulation. Such a cable comprises an inner conductor composed of one or more strand parts, an inner semiconducting layer surrounding the conductor, a solid insulating layer surrounding this and an outer semiconducting layer surrounding the insulating layer. Such cables are flexible, which is an important property in this context since the technology for the device according to the invention is based primarily on winding systems in which the winding is formed from cable which is bent during assembly. The flexibility of a XLPE-cable normally corresponds to a radius of curvature of approximately 20 cm for a cable 30 mm in diameter, and a radius of curvature of approximately 65 cm for a cable 80 mm in diameter. In the present application the term "flexible" is used to indicate that the winding is flexible down to a radius of curvature in the order of four times the cable diameter, preferably eight to twelve times the cable diameter.

The winding should preferably be constructed to retain its properties even when it is bent and when it is subjected to thermal stress during operation. It is vital that the layers retain their adhesion to each other in this context. The material properties of the layers are decisive here, particularly their elasticity and relative coefficients of thermal expansion. In a XLPE-cable, for instance, the insulating layer consists of cross-linked, low-density polyethylene, and the semiconducting layers consist of polyethylene with soot and metal particles mixed in. Changes in volume as a result of temperature fluctuations are completely absorbed as changes in radius in the cable and, thanks to the comparatively slight difference between the coefficients of thermal expansion in the layers in relation to the elasticity of these materials, radial expansion

can take place without the adhesion between the layers being lost.

The material combinations stated above should be considered only as examples. Other combinations fulfilling the conditions specified and also the condition of being semiconducting, i.e. having resistivity within the range of 10^{-1}-10^{6} ohm-cm, e.g. 1-500 ohm-cm, or 10-200 ohm-cm, naturally also fall within the scope of the invention.

The insulating layer may consist, for example, of a solid thermoplastic material such as low-density polyethylene (LDPE), high-density polyethylene (HDPE), polypropylene (PP), polybutylene (PB), polymethyl pentene (PMP), cross-linked materials such as cross-linked polyethylene (XLPE), or rubber such as ethylene propylene rubber (EPR) or silicon rubber.

The inner and outer semiconducting layers may be of the same basic material but with particles of conducting material such as soot or metal powder mixed in.

The mechanical properties of these materials, particularly their coefficients of thermal expansion, are affected relatively little by whether soot or metal powder is mixed in or not - at least in the proportions required to achieve the conductivity necessary according to the invention. The insulating layer and the semiconducting layers thus have substantially the same coefficients of thermal expansion.

Ethylene-vinyl-acetate copolymers/nitrile rubber, butyl graft polyethylene, ethylene-butyl-acrylate-copolymers and ethylene-ethyl-acrylate copolymers may also constitute suitable polymers for the semiconducting layers.

Even when different types of material are used as base in the various layers, it is desirable for their coefficients of thermal expansion to be substantially the same. This is the case with combination of the materials listed above.

The materials listed above have relatively good elasticity, with an E-modulus of E<500 MPa, preferably <200 MPa. The elasticity is sufficient for any minor differences between the coefficients of thermal expansion for the materials in the layers to be absorbed in the radial direction of the elasticity so that no cracks appear, or any other damage, and so that the layers are not released from each other. The material in the layers is elastic, and the adhesion between the layers is at least of the same magnitude as the weakest of the materials.

The conductivity of the two semiconducting layers is sufficient to substantially equalize the potential along each layer. The conductivity of the outer semiconducting layer is sufficiently great to enclose the electrical field in the cable, but sufficiently small not to give rise to significant losses due to currents induced in the longitudinal direction of the layer.

Thus preferably, each of the two semiconducting layers essentially constitutes one equipotential surface and the winding, with these layers, will substantially enclose the electrical field within it.

There is, of course, nothing to prevent one or more additional semiconducting layers being arranged in the insulating layer.

The application on such cables thus constitutes preferred embodiments of the invention.

~~These and other preferred embodiments of the machine~~ according to ~~the~~ invention are defined in the sub~~claims to claim 1.~~

Ins. B4

~~In a second aspect~~ of the invention ~~the object~~ striven for is achieved by a method of manufactu~~ring a~~ rotating electric machine of the type ~~de~~scribed in the preamble to claim ~~19 in~~cluding the specific measures defined in ~~the characterizing part of this claim.~~

According to a preferred embodiment of the method the cuff means are lubricated with an anti-friction agent, thereby facilitating drawing the cable through them and also reducing the risk of it being damaged during this operation.

Cuff means in accordance with the preferred embodiments of the machine are used in other preferred embodiments of the method according to the invention.

The invention will now be explained in more detail in the following description of a preferred embodiment, with reference to the accompanying drawings in which

Figure 1 shows a schematic end view of a sector of the stator in a machine according to the invention,

Figure 2 shows a cross section through a cable used in the machine according to the invention,

Figure 3 shows a part section along the line III-III in Figure 2,

Figure 4 shows a part section along the line IV-IV in Figure 3.

In the schematic axial view shown in Figure 1 through a sector of the stator 1 of the machine, its rotor is designated 2. The stator is conventionally composed of a laminated core of core sheet. The figure shows a sector of the machine corresponding to one pole division. From a yoke part 3 of the core, situated radially outermost, a number of teeth 4 extend radially inwards towards the rotor 2, the teeth being separated by slots 5 in which the stator winding is arranged. The cables 6 in the windings are high-voltage cables and may be of substantially the same type of high-voltage cables as those used for power distribution, e.g. XLPE cables. One difference is that the outer, mechanically protective sheath and metal screen that normally surround such a cable are omitted. The cable thus consists only of a conductor, an inner semiconducting layer, an insulating layer and an outer semiconducting layer. The semiconducting layer sensitive to mechanical damage on the outside of the cable is thus exposed.

In the figure the cables 6 are indicated schematically, only the central, conducting part of the cable part or coil side being drawn in. As can be seen, each slot 5 has varying cross section with alternating wide parts 7 and narrow parts 8. The wide parts 7 are substantially circular and surround the cable lead-throughs, the waist parts between these thus forming narrow parts 8. The waist parts serve to radially position each cable lead-through. The cross section of the slot as a whole also becomes narrower radially inwards. This is because the voltage in the cable lead-throughs is lower the closer they are situated to the radially innermost part of the stator. Slim cable lead-throughs can therefore be used here, whereas thicker ones are necessary further out. Cables of three different dimensions are used

in the example illustrated, arranged in three sections 9, 10, 11 of the slot 5 dimensioned to fit them.

Figure 2 shows a cross section through a high-voltage cable 6 used according to the present invention. The high-voltage cable 6 a number of strand parts 31 made of copper (Cu), for instance, and having circular cross section. These strand parts 31 are arranged in the middle of the cable 6. Around the strand parts 31 is a first semiconducting layer 32. Around the first semiconducting layer 32 is an insulating layer 33, e.g. XLPE-insulation, and around the insulating layer 33 is a second semiconducting layer 34. The concept of "high-voltage cable" in the present application need not therefore include the metal screen and the outer sheath that normally surround such a cable for power distribution.

Figure 3 shows a cross section through a cuff according to the invention. The section is taken along the line III-III in Figure 1 and extends a short way in from one end surface of the stator 1. The external shape 15 of the cuff corresponds to that of the slot 5, i.e. similar to a bicycle chain, where the section runs laterally through one of the wide parts of the "bicycle chain", as shown in Figure 4 where the position of the section in Figure 3 is also indicated. The cuff is arranged close to one end 19 of the stator 1 and a similar cuff is arranged at the opposite end of the stator. The cuff extends radially along the entire slot 5 and each slot is provided with such a cuff. The axial extension of the cuff is approximately 4 cm and normally lies within the interval 2-6 cm. The laminated core of the stator is designated 18 and an end plate 12 of fiber material is arranged at its ends. The cuff is incorporated in the end plate 12. A recess 17 is provi-

ded in the part of the slot 5 extending through the end plate. The recess runs in the slot wall along the entire radial length of the slot 5. The cuff is provided with a collar 16 fitting into the recess 17. From the collar 16 the lining part 13 of the cuff stretches out towards the end surface 19 of the stator and terminates immediately prior to this. The cuff may alternatively terminate on a level with the end surface of the stator, or extend a short way outside this. The lining 13 of the cuff tightly abuts the slot wall along its entire length.

The inside 14 of the cuff widens slightly towards the end surface 19 of the stator, at an angle of a few degrees. The inside of the cuff is thus slightly conical at the areas around the cable lead-throughs. Where the cuff is to receive the cable 6, its smallest inner diameter close to the collar may correspond approximately to the outer diameter of the cable 6, or may be somewhat less to ensure good sealing and efficient support. The cuff is made of an elastic material, suitably silicon rubber. It is important that the material does not contain any remnants of process oil since this can diffuse in towards the outer semiconducting layer 34 of the cable, attacking and damaging this. The material should also be thermally stable.

Between the cable positions in the cuff, i.e. in the narrower parts, the cuff has waist portions 20, (see Figure 4) that fill out the slot at these points, ensuring that it is completely sealed.

When the cuffs are fitted, which is performed before the stator is wound, they are squeezed together and pushed axially into the slot 5 until the collar 16 of the cuff snaps into the recess 17 in the slot, and it

is thus locked in place. When the cuffs have been applied the cable can be wound, the cuffs functioning as guides. The cable is thus correctly guided and prevented from coming into contact with the edge between the slot and the end surface of the stator, thereby eliminating risk of damage. It may be advisable to lubricate the inside of the cuff to facilitate insertion of the cable. A lubricant should be selected which does not influence the outer semiconducting layer of the cable. Suitable lubricants are talcum or boron nitride.

The cuff described above extends in radial direction along the entire slot. Alternatively an individual cuff may be arranged for each cable lead-through and is in that case cylindrical. The invention does not exclude other alternatives for securing the cuffs than by means of the collar described. They can be glued to the slot, for instance, or retained solely by friction.